DESCRIPTION

DISPLACEMENT DETECTOR

TECHNICAL FIELD

The present invention relates to a non-contact type displacement detector

5   for detecting a displacement of a moving body.

BACKGROUND ART

In the past, a displacement detector has been proposed to detect a change in impedance of a coil portion caused by inserting a core into the coil portion, thereby providing a signal indicative of position data of the core relative to the

10   coil portion.

This kind of displacement detector is disclosed in US Patents No.5,003,258, No.4,864,232, and No.5,893,300. For example, as shown in , FIG. 43, in a position detector disclosed in US patent No.5,003,258, a coil portion **2** is formed such that a change in impedance **Z** (inductance component)

15   with respect to temperature resulting from a magnetic material **21** of a core **1** is cancelled by a change in impedance **Z** (eddy current component) with respect to temperature resulting from a nonmagnetic material **22**. That is, against a problem that a temperature coefficient of the impedance **Z** of the coil portion depends on displacement of the core **1**, the dependency of the temperature

20   coefficient of the impedance **Z** on the displacement is reduced by modifying structures of the coil portion and its circumference. However, it leads to an increase in the total number of parts, and makes difficult to carry out the positioning of the parts. In addition, there are problems of a reduction in degree of freedom of design of the coil portion, increase in cost performance,

25   and deterioration in versatility.

In addition, as another prior art, Japanese Patent Early Publication [kokai] 2000-186903 discloses a non-contact type position sensor using high-frequency magnetic field. As shown in FIG. 44, this position sensor is provided with a rotating shaft **201** rotated in conjunction with an object to be

30   detected, arc-shaped, movable metal body **202** coupled with the rotating shaft

201 through a coupling member **202c** to be moved on the circumference of a circle having the axis of the rotating shaft **201** as its center in conjunction with the rotation of the rotating shaft, a pair of sensor coils **203** (**203a**, **203b**) fixed on the circumference of the circle, and having a center axis curved such that

5 arms (**202a**, **202b**) of the movable metal body **202** can come in and go out of through holes of the respective sensor coils to change an occupied area in a magnetic path, a sensor circuit for detecting a magnetic change caused depending on the occupied area of the arms **202a**, **202b** in the sensor coils **203a**, **203b** by activating those sensor coils to generate a RF modulated

10 magnetic field, and resistances **205a**, **205b** for detecting coil currents flowing in the sensor coils **203a**, **203b**. According to this sensor, since the arms **202a**, **202b** of the movable metal body **202** are complementarily inserted in the sensor coils **203a**, **203b**, and the sensor circuit **204** detects a change in impedance of each of the sensor coils **203a**, **203b**, there is an advantage that

15 accurate positioning is not needed.

However, in an angle status where the arms **202a**, **202b** of the movable metal body **202** are not inserted in the sensor coils **203a**, **203b**, the coil impedances of the sensor coils **203a**, **203b** are only the impedance of the coil wire. Therefore, temperature characteristics (temperature coefficients) thereof

20 depend on only a factor of the coil wire. On the other hand, in an angle status where the arms **202a**, **202b** are inserted in the sensor coils **203a**, **203b**, the coil impedance of the sensor coils **203a**, **203b** has an increase in coil impedance (an increase in inductance, eddy current loss, hysteresis loss, and so on) caused by the insertions of the arms **202a**, **202b**, in addition to the

25 impedance of the coil wire. In this case, since the temperature coefficient is determined by a sum of different temperature coefficients of the factors causing the increase in impedance, it is different from the temperature coefficient in the angle status where the arms **202a**, **202b** are not inserted in the sensor coils **203a**, **203b**. This means that the temperature coefficient changes depending

30 on the insertion amount (angle). Even if digital trimming is performed to

achieve a temperature compensation by a compensation circuit **210** of the sensor circuit **204**, there is a problem that an accurate output can not be provided to ECU unless a complicated compensation for changing an amplification rate in response to the angle is performed. Thus, the

5 conventional sensor still has room for improvement.

SUMMARY OF THE INVENTION

Therefore, in the above viewpoints, a concern of the present invention is to provide a displacement detector having the capability of compensating a change in temperature coefficient of the impedance of a coil portion relative to a

10 displacement of a coil, thereby improving detection accuracy.

That is, the displacement detector of the present invention comprises:

a constant-current supply unit configured to output a constant current including an alternating current,

a coil portion, to which the constant current is supplied,

15 a magnetic core supported to be movable relative to the coil portion in a movable range, and

a signal processing circuit configured to determine a displacement of the core to the coil portion in accordance with a change in output voltage of the coil portion under a condition of supplying the constant current to the coil portion.

20 The constant-current supply unit supplies the constant current, which is obtained by superimposing a direct current on the alternating current, to the coil portion. A fluctuation width of temperature coefficient of a peak value (V1) of the output voltage of the coil portion, which is a total of DC and AC voltage components (Vdc, Vac), in the movable range is smaller than the fluctuation

25 width of temperature coefficient of the AC voltage component (Vac) in the movable range.

According to the present invention, it is possible to increase a degree of freedom of design of the coil portion, and readily reduce the displacement dependency of the temperature coefficient of impedance of the coil portion by

30 setting circuit constants. As a result, a change in temperature coefficient of

the impedance of the coil portion depending on the displacement of the core can be compensated by a simple circuit.

Specifically, in the above displacement detector, it is preferred that at least one of a ratio between the alternating current and a direct current in the constant current, a ratio between AC and DC components of an impedance of the coil portion, a temperature characteristic of the ratio between the alternating current and the direct current in the constant current, and a temperature characteristic of the ratio between the AC and DC components of the impedance of the coil portion is determined such that the fluctuation width of temperature coefficient of the peak value (V1) is smaller than the fluctuation width of temperature coefficient of the AC voltage component (Vac).

In addition, as a preferred embodiment of the above displacement detector, the coil portion comprises a curved coil having a curvature, the core has the same curvature as the curved coil, and is rotatable about a rotation axis, and an insertion amount of the core into the curved coil is changed by rotating the core about the rotation axis. In this case, it is possible to increase a change in impedance of the coil. It is also preferred that the temperature coefficient of the DC voltage component of the output voltage of the coil portion is closer to the temperature coefficient of the AC voltage component of the output voltage of the coil portion in the case of a maximum insertion amount of the core into the curved coil than the temperature coefficient of the AC voltage component of the output voltage of the coil portion in the case of a minimum insertion amount of the core into the curved coil. The fluctuation width of the temperature coefficient of the peak value of the output voltage of the coil portion can be reduced.

In a preferred embodiment of the above displacement detector, the constant-current supply unit comprises an oscillating circuit configured to generate a voltage obtained by superimposing a DC voltage on an AC voltage, and a voltage/current conversion circuit. A ratio between the AC and DC voltages in the voltage is determined such that the fluctuation width of the

temperature coefficient of the peak value (V1) is smaller than the fluctuation width of the temperature coefficient of the AC voltage component (Vac). In this case, it is preferred that the AC voltage generated by the oscillating circuit is a triangular wave.

5   As another preferred embodiment of the above displacement detector, the constant-current supply unit comprises an oscillating circuit configured to generate a voltage obtained by superimposing a DC voltage on an AC voltage, and a voltage/current conversion circuit. The oscillating circuit has a resistance, by which a value of the DC voltage is determined. The temperature

10   coefficient of a value of the resistance is determined such that the fluctuation width of the temperature coefficient of the peak value (V1) is smaller than the fluctuation width of the temperature coefficient of the AC voltage component (Vac).

        In a further preferred embodiment of the above displacement detector, the

15   constant-current supply unit comprises an oscillating circuit configured to generate a voltage obtained by superimposing a DC voltage on an AC voltage, and a voltage/current conversion circuit. A temperature characteristic of frequency of the AC voltage is determined such that the fluctuation width of the temperature coefficient of the peak value (V1) is smaller than the fluctuation

20   width of the temperature coefficient of the AC voltage component (Vac). In this case, even when it is hard to set the circuit constants because the constant-current supply unit is composed of an integrated circuit (IC), it is possible to set the temperature characteristic of the AC component of the impedance of the coil portion by selecting temperature coefficients of a

25   resistance and a capacitor for determining an oscillating frequency of the AC voltage subject to the condition that these resistance and capacitor are placed outside.

        In a still another preferred embodiment of the above displacement detector, the constant-current supply unit comprises a DC constant-current circuit and

30   an AC constant-current circuit. At least one of a temperature characteristic of

a value of direct current provided from the DC constant-current circuit, a temperature characteristic of frequency of an alternating current provided from the AC constant-current circuit, and a temperature characteristic of a value of the alternating current provided from the AC constant-current circuit is determined such that the fluctuation width of the temperature coefficient of the peak value (V1) is smaller than the fluctuation width of the temperature coefficient of the AC voltage component (Vac). In this case, it is preferred that the alternating current output from the AC constant-current circuit is a triangular wave.

In addition, as a preferred embodiment of the above displacement detector, the coil portion comprises a coil and a circuit element connected in series with the coil and having no dependency of impedance on displacement of the core. At least one of DC and AC components of the impedance of the circuit element, and temperature coefficients of the DC and AC components of the impedance of the circuit element is determined such that the fluctuation width of the temperature coefficient of the peak value (V1) is smaller than the fluctuation width of the temperature coefficient of the AC voltage component (Vac).

In a preferred embodiment of the above displacement detector, the circuit element is one of a resistance and an inductor. In this case, it is possible to control the AC impedance of the DC resistance of the coil portion at a moderate price.

In a further preferred embodiment of the above displacement detector, the constant-current supply unit is provided by an integrated circuit comprising resistances setting a magnitude of a direct current, frequency and amplitude of an alternating current, and digital trimming unit configured to set values of the resistances. The values of the resistances are determined by the digital trimming unit such that the fluctuation width of the temperature coefficient of the peak value (V1) is smaller than the fluctuation width of the temperature coefficient of the AC voltage component (Vac).

In the above displacement detector, it is preferred that the signal

processing circuit comprises a rectifying circuit and a circuit configured to peak-hold an output of the rectifying circuit.

In the above displacement detector, it is preferred that the signal processing circuit has an amplifier with a temperature coefficient that is in a reverse polarity relation with the temperature coefficient of the peak value of the output voltage of the coil portion. The signal processing circuit outputs a displacement signal indicative of position data of the core relative to the coil portion in accordance with an output of the amplifier. Since the output of the amplifier depends on only the temperature-compensated displacement, it is possible to obtain a temperature-compensated displacement signal by processing this output.

Another concern of the present invention is to provide a displacement with another components for achieving the same purpose as the above. That is, the above-described displacement detector is characterized by supplying the constant current obtained by superimposing the direct current on the alternating current to the coil portion. On the other hand, the present displacement detector is characterized by adding a level shift voltage (Vsh) to a characteristic value (V1) extracted from the output voltage of the coil portion.

That is, the displacement detector of the present invention comprises:

a constant-current supply unit configured to output a constant current including an alternating current;

a coil portion, to which the constant current is supplied;

a magnetic core supported to be movable relative to the coil portion in a movable range; and

a signal processing circuit configured to determine a displacement of the core to the coil portion in accordance with a change in output voltage of the coil portion under a condition of supplying the constant current to the coil portion. This displacement detector further comprises a characteristic-value extracting unit configured to extract a characteristic value (V1) from the output voltage of the coil portion, and a level shift circuit configured to add a level shift voltage

(Vsh) to the characteristic value. A fluctuation width of temperature coefficient of a total (V2) of the characteristic value (V1) and the level shift voltage (Vsh) in the movable range is smaller than the fluctuation width of temperature coefficient of the characteristic value in the movable range.

According to the present invention, it is possible to avoid the occurrence of inconvenience that electric current consumption changes due to an adjustment of the temperature characteristic. In addition, since the adjustment is carried out without depending on the temperature coefficient of the DC resistance of a wiring material, there is an effect that a change in temperature coefficient of the impedance of the coil portion relative to the displacement of the coil can be compensated by a simple circuit. In other words, to achieve the purpose of the present invention, a relatively small level shift value is added to the characteristic value by the level shift circuit. Therefore, it is particularly effective when there is a limitation in electric current consumption. Thus, a further advantage can be presented in comparison with the displacement detector comprising the constant-current supply unit for supplying, to the coil portion, the constant current obtained by superimposing the direct current on the alternating current.

It is preferred that the above-described displacement detector further comprises a unit configured to adjust at least one of a temperature coefficient and a magnitude of the level shift voltage. By reducing variations in temperature characteristic due to production lot, the temperature characteristic can be adjusted with higher accuracy. Alternatively, a magnitude of digital quantity of the level shift voltage may be adjusted by the level shift circuit.

In the above displacement detector, it is preferred that the signal processing circuit comprises a peak-hold circuit as the characteristic-value extracting unit, A/D conversion circuit configured to convert the characteristic value into a digital signal, which is disposed between the peak-hold circuit and the level shift circuit, and a temperature compensation circuit configured to perform a temperature compensation to an output of the level shift circuit. In

this case, it is possible to readily perform calibration with accuracy.

In the displacement detector described above, it is preferred that the characteristic value is one of a peak value of the output voltage of the coil portion, bottom value of the output voltage of the coil portion, and a value proportional to an amplitude of the output voltage of the coil portion.

In each of the displacement detectors described above, it is preferred that the coil portion has a curved coil having a curvature, and the curved coil is fixed to a housing having a unit configured to correct a change in curvature of the curved coil. In this case, it is possible to correct or prevent the change in curvature of the curved coil.

As a preferred embodiment of each of the above displacement detectors, the core is provided by a plurality of curved cores having a same curvature, which are supported to be rotatable about a single rotation axis. The coil portion comprises a plurality of coils having a same curvature as the curved cores, which are spaced from each other in the axial direction of the rotation axis. Insertion amounts of the curved cores into the coils are changed by rotating the curved cores about the rotation axis. In this case, an opening angle of the winding wire of the curved coil and a mechanical rotation angle of a movable block can be increased. Therefore, a wide range of the rotation angle with good impedance linearity of the coil portion is obtained. In addition, when two coils having the same specification are used, their coil characteristics are identical to each other. Therefore, there are advantages in the aspects of winding process and cost performance.

In another preferred embodiment of each of the above displacement detectors, the coil portion is provided by a pair of inner and outer coils having different curvatures and disposed to be curved in substantially parallel with each other. The core comprises a first core curved at a same curvature as the inner core and supported to be rotatable about a rotation axis, and a second core curved at a same curvature as the outer core and supported to be rotatable about the rotation axis. An insertion amount of the first core into the

inner core is changed by rotating the first core about the rotation axis, and an insertion amount of the second core into the outer core is changed by rotating the second core about the rotation axis. In this case, an opening angle of the winding wire of the curved coil and a mechanical rotation angle of a movable

5   block can be increased. In addition, it is possible to provide a thinned displacement detector.

In a further preferred embodiment of each of the above displacement detectors, the signal processing circuit comprises a signal compensation circuit composed of an A/D conversion circuit configured to convert a peak value of

10   the output voltage of the coil portion into a digital signal, and a compensation circuit configured to for digital trimming the digital signal. In a system (ECU) for receiving and treating an output of the displacement detector, which is composed of a digital circuit, when the output of the displacement detector is an analog signal, there is a fear that an error or a response delay occurs due to

15   additional repetition of A/D conversion or D/A conversion. However, in this embodiment, since the output of the displacement detector is a digital signal, such a problem does not occur. In addition, the influence of external noise at the time of signal transmission can be prevented, as compared with the case of outputting the analog signal.

20   Further characteristics of the present invention and effects brought thereby will be clearly understood from the best mode for carrying out the invention described below.

BREIF EXPLANATION OF THE DRAWINGS

FIG. 1 is a circuit diagram of a displacement detector according to the first

25   embodiment of the present invention;

FIG. 2 is a top view of the displacement detector;

FIG. 3 is a cross-sectional view of the displacement detector taken along the line A-A' in FIG. 2;

FIG. 4 is a partially enlarged view of FIG. 3;

30   FIG. 5 is a waveform diagram of an output voltage from a coil of the

displacement detector;

FIG. 6 is a graph showing a relation between impedance of the coil and rotation angle of a core of the displacement detector;

FIG. 7 is a graph showing a relation between output voltage of the coil and rotation angle of the core of the displacement detector;

FIG. 8 is a graph showing a relation between temperature coefficient of the output voltage of the coil and rotation angle of the core of the displacement detector;

FIG. 9 is a graph showing a relation between temperature coefficient of a peak voltage of the coil and rotation angle of the core of the displacement detector;

FIG. 10 is a circuit diagram illustrating an constant-current circuit and a signal processing circuit of the displacement detector;

FIG. 11 is a circuit diagram illustrating an oscillating circuit of the displacement detector;

FIG. 12 is a circuit diagram illustrating a voltage-current conversion circuit of the displacement detector;

FIG. 13 is a circuit diagram illustrating another constant-current circuit of the displacement detector;

FIG. 14 is a diagram illustrating another circuit configuration of the displacement detector;

FIG. 15 is a reference diagram showing a relation between temperature coefficient of the output voltage of the coil and rotation angle of the core;

FIG. 16 is a diagram showing an equivalent circuit of a coil according to the second embodiment of the present invention;

FIG. 17 is a graph showing a fluctuation of a resistance value of a copper wire caused by a skin effect;

FIG. 18 is a graph showing a fluctuation of the resistance value of the copper wire caused by a proximity effect;

FIG. 19 is a circuit diagram of the displacement detector according to the first embodiment of the present invention;

FIG. 20 is a circuit diagram of a displacement detector according to the third embodiment of the present invention;

FIG. 21 is a top view of the displacement detector;

FIG. 22 is a graph showing a relation between AC impedance of a coil and
5   rotation angle of a core of the displacement detector;

FIG. 23 is a graph showing a relation between temperature coefficient of an output voltage of the coil and rotation angle of the core of the displacement detector of FIG. 19;

FIG. 24 is a graph showing a relation between temperature coefficient of an
10 output signal of a peak-hold circuit and rotation angle of the core of the displacement detector of FIG. 20;

FIG. 25 is a graph showing a relation between temperature coefficient of the output signal of the peak-hold circuit and rotation angle of the core of the displacement detector of FIG. 20;

15 FIG. 26 is another circuit diagram of the displacement detector;

FIG. 27 is a circuit diagram of a displacement detector according to the fourth embodiment of the present invention;

FIG. 28 is a diagram showing characteristics of magnetic materials used for cores in the fifth embodiment of the present invention;

20 FIGS. 29A to 29E are graphs each showing a relation of linearity between AC impedance of the coil and angle span of the magnetic materials at the respective frequency;

FIGS. 30A to 30D are end-shape views of cores;

FIG. 31 is a cross-sectional view of a linear-stroke type displacement detector;

25 FIGS. 32A to 32E are end-shape views of the cores with removed edges;

FIG. 33 is a plan view of a coil having supporting/fixing members at its both end portions;

FIG. 34 is a top view of a displacement detector with a pair of coil portions according to the sixth embodiment of the present invention;

30 FIG. 35 is a partially cross-sectional view of the displacement detector of FIG.

34;

FIG. 36 is a top view of another displacement detector with a pair of coil portions according to the sixth embodiment of the present invention;

FIG. 37 is a partially cross-sectional view of the displacement detector of FIG. 36;

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FIGS. 38A and 38B are diagrams showing displacement signals in the seventh embodiment of the present invention;

FIGS. 39A and 39B are diagrams showing another displacement signals in the seventh embodiment of the present invention;

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FIGS. 40A and 40B are diagrams showing still another displacement signals in the seventh embodiment of the present invention;

FIG. 41 is a cross-sectional view of a displacement detector according to the eighth embodiment of the present invention;

FIG. 42 is a circuit diagram of the displacement detector of FIG. 41;

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FIG. 43 is a cross-sectional view of a conventional displacement detector; and

FIG. 44 is a schematic diagram of another conventional displacement detector.

BEST MODE FOR CARRYING OUT THE INVENTION

A displacement detector of the present invention is explained in detail according to the following preferred embodiments, referring to the attached

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drawings.

(First Embodiment)

As shown in FIGS. 1 to 4, a displacement detector of the present embodiment has a coil **2**, movable block **13**, and a magnetic core **1**. The coil **2** is wound around a curved bobbin **10** curved at a constant curvature and

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having a U-shaped cross section, on the inside of which a coating **11** is formed. The movable block **13** is composed of a cylinder solid having a center of the curvature of the curved coil **2** as a rotation axis, and a projection **13a** formed on the outer surface of the cylinder solid. The magnetic core **1** is connected at its one end to the projection **13a**, and curved at a constant curvature such that

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the magnetic core can be inserted in a cavity portion of the curved coil **2**. The

displacement detector further includes a curvature correcting member **12** for correcting a change in curvature of the coil **2**, housing **14** having a mounting surface, on which respective parts are mounted, constant-current circuit **3** for providing, to the coil **2**, a constant current **Id** obtained by superimposing an

5   alternating current **Iac** having required frequency **f** and amplitude on a required magnitude of a direct current **Idc**, and a signal processing circuit **4** for providing a displacement signal **Vout** indicative of position data of the core **1** relative to the coil **2** in response to a peak value **V1** of a voltage **Vs** (detecting signal) detected at both ends of the coil **2**, which is determined by the constant

10   current **Id** provided from the constant-current circuit **3** and the impedance **Z** of the coil **2**.   The coil **2** includes a coil potion **A**, to which the constant current **Id** is supplied, and from which the detecting signal is output.   The curved bobbin **10** may have a cross section other than the U-shape.   As a winding wire of the coil, for example, it is preferred to use nichrome, Manganin, or a copper-nickel

15   alloy.   In the present embodiment, as the rotation angle Θ of the movable block **13** changes from 0° to 90°, a region of the coil **1** inserted in the core **2** decreases.

The constant-current circuit **3** is composed of an oscillating circuit **3a** for generating a constant voltage **Vd'** obtained by superimposing an AC voltage

20   **Vac'** having required frequency **f** and amplitude on a required magnitude of a DC voltage **Vdc'**, and a voltage-current conversion circuit **3b** for converting the constant voltage **Vd'** provided from the oscillating circuit **3a** into the constant current **Id**.

In the above displacement detector, as shown in FIG. 1, the alternating

25   current **Iac** and the direct current **Idc** are simultaneously supplied from the constant-current circuit **3** to the coil **2**.   When **"Zdc"** designates DC resistance of the coil **2**, **"Zac"** designates AC impedance at the oscillation frequency **f** of the AC current **Iac**, and **"Vs"** designates the voltage detected at the both ends of the coil **2**, the voltage **Vs** is a sum of the DC voltage **Vdc** and the AC voltage **Vac**, as

30   represented by the following equation.

$$Vs = Vdc + Vac = Idc * Zdc + Iac * Zac \quad \cdots (1)$$

In the equation (1), values are complex numbers. However, when considering only the peak voltage **V1** of the voltage **Vs**, the voltage **V1** is represented by the equation (2).

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$$V1 = Vdc + Vac = Idc * Zdc + Iac * Zac \quad \cdots (2)$$

In the Equation (2), values can be handled as real numbers. Therefore, as shown in FIG. 5, the waveform has the peak voltage **V1** that is the sum of the DC voltage **Vdc** and the AC voltage **Vac**.

The displacement detector of the present embodiment is characterized in

10   that a fluctuation width of temperature coefficient of the peak value (**V1**) of the output voltage of the coil **2**, which is the sum of the DC voltage component (**Vdc**) and the AC voltage component (**Vac**), in the movable range is smaller than the fluctuation width of temperature coefficient of the AC voltage component (**Vac**) in the movable range.

15   By the way, in the displacement detector, an output linearity error of a signal detected in a required displacement zone is regulated at room temperature. By giving a constant margin to it, the regulation becomes possible over the entire operation temperature range. For example, it can be regulated as follows: "when an angle range Θ for position detection = 0° to 90°,

20   the linearity error of the detected signal is ±1%FS or less at room temperature, and ±2%FS or less in the range of -40°C to +130°C". This means that a deterioration of the linearity error due to temperature fluctuation factors must be controlled within a range of approximately ±1%FS. In addition, when the room temperature is 30°C, there is a temperature width of 100°C at the high

25   temperature side. Assuming that the detected signal of the coil portion **A** linearly changes with respect to temperature, it means that a fluctuation width of temperature change ratio (temperature coefficient) must be controlled within a range of ±100ppm/K.

In addition, with respect to a displacement in a required displacement

30   zone, when the fluctuation width $\Delta(dV1/dT)$ of the temperature coefficient of the

peak value of **V1** of the voltage **Vs** detected at both ends of the coil **2** is within the range of ±100 ppm/K, it is possible to obtain a temperature-compensated voltage within the range of a room temperature value for the displacement ± 100 ppm/K by the addition of a simple temperature compensation circuit

5   having a constant temperature coefficient. This is a goal of the present invention.

FIG. 6 is a sample data prepared from actual measurement value of impedance of the coil **2** obtained by winding a copper-nickel alloy wire (GCN 15 wire). In this graph, the DC resistance **Zdc** and the AC impedance **Zac** of the

10   coil **2** are plotted, and the horizontal axis is the rotation angle Θ of FIG. 2. The impedance was set to perfectly linearly change with respect to the rotation angle Θ. This is fairly close to the actual measurement value. In FIG. 6, **Zac** and **Zdc** at the ambient temperatures; -40°C, +25°C, +85°C, +130°C are respectively shown.

15   At the ambient temperature + 25°C, the DC resistance **Zdc** is 188 Ω, the temperature coefficient is 511 ppm/K, and the AC impedance **Zac** is represented by:

$$Zac = (Z0 + Z'*\Theta) * \{1 + (\beta0 + \beta'*\Theta)*T\} \quad \cdots(3)$$

wherein Z0 = 636 Ω, Z'=-3.48 Ω/deg, β0=478 ppm/K, β'=-2.49 ppm/K/deg, Θ is

20   the rotation angle, and T is ambient centigrade temperature. In addition, the temperature coefficient of the AC impedance **Zac** is 478 ppm/K at Θ=0°, and 254 ppm/K at Θ=90°. Therefore, the fluctuation width Δ (dZac/dT) reaches 224 ppm/K.

Next, under a condition that the constant-current circuit **3** outputs 1.5

25   mA of the direct current **Idc**, and 0.3 mA of the alternating current **Iac**, results of the DC voltage **Vdc**, AC voltage **Vac**, and the peak voltage **V1** detected at both ends of the coil **2** are plotted in FIG. 7 by use of the above equation (2), in which the temperature change ratios of the frequency **f**, direct current **Idc** and the alternating current **Iac** are zero for simplicity. FIG. 8 shows the

30   temperature coefficients of them.

As understood from FIG. 8, the temperature coefficient of the peak voltage **V1** is approximately 450 to 500 ppm/K over the rotation angle Θ= 0° to 90°, and the fluctuation width Δ (dV1/dT) is approximately 50 ppm/K, which is much narrower than the fluctuation width of the AC impedance **Zac**.

5   Therefore, by performing a temperature compensation of 470 ppm/K to the peak voltage **V1**, the compensated voltage practically equal to the room temperature value can be obtained without error.

Under a condition of changing the direct current **Idc**, while keeping 0.3 mA of the alternating current **Iac** output from the constant-current circuit **3**,

10   results of the temperature coefficient of the peak voltage **V1** calculated in the same manner as FIG. 8 are plotted in FIG. 9. When the direct current **Idc** = 0, displacement dependency of the temperature coefficient is identical to the displacement dependency of the impedance **Z** of the coil **2**. However, as the direct current **Idc** increases, it becomes closer to the temperature coefficient of

15   the DC voltage **Vdc**. In addition, as the insertion amount of the core **1** in the coil **2** decreases (In this embodiment, as the rotation angle Θ increases), the influence of the DC voltage **Vdc** easily occurs because a percentage of the DC voltage **Vdc** in the peak voltage **V1** is larger.

When the direct current **Idc** is slightly mixed, the fluctuation width Δ

20   (dV1/dT) of the temperature coefficient of the peak voltage **V1** can be considerably improved in comparison with the case of the direct current **Idc** = 0. As the direct current **Idc** increases, the fluctuation width Δ(dV1/dT) of the temperature coefficient of the peak voltage **V1** is smaller, and then saturated at a level. Therefore, since there is a case that increasing the direct current **Idc**

25   leads to an increase of electric current consumption, an appropriate value of the direct current **Idc** should be selected in consideration of a permissible electric-current consumption and the value of fluctuation width Δ (dV1/dT) of the temperature coefficient of the peak voltage **V1**. At this time, by respectively setting the DC voltage **Vdc'** and the AC voltage **Vac'** generated by the oscillating

30   circuit **3a**, it is possible to determine a ratio between the direct current **Idc** and

the alternating current **Iac** of the constant current **Id**.

In addition, as the frequency **f** of the AC voltage **Vac'** generated by the oscillating circuit **3a** is higher, a proportion of the AC voltage **Vac** to the DC voltage **Vdc** increases. Therefore, by appropriately selecting the frequency **f**, it 5 is possible to properly determine the ratio between **Vdc** and **Vac**. In the above explanation, the temperature change ratio of each of the frequency **f**, direct current **Idc** and the alternating current **Iac** are zero. However, when these have the temperature coefficients, each of the temperature coefficients of the DC voltage **Vdc** and the AC voltage **Vac** shifts up and down in FIG. 8, so that a 10 change in temperature characteristic of the peak voltage **V1** occurs.

As understood from FIGS. 8 and 9, when the insertion amount of the core **1** is small, (dV1/dT) considerably receives the influence of (dVdc/dT), and when the insertion amount of the core **1** is large, it considerably receives the influence of (dVac/dT). This can be clearly understood from the composition 15 ratio of the DC voltage **Vdc** and the AC voltage **Vac** in the peak voltage **V1**.

Regardless of the insertion amount of the core **1**, the value of (dV1/dT) exists between the values of (dVdc/dT) and (dVac/dT). When minimizing a difference between the value of (dVac/dT) and the value of (dVdc/dT) in the case of a large insertion amount of the core **1** (at the vicinity of the rotation 20 angle $\Theta = 0°$ in this embodiment), (dV1/dT) becomes a value close to (dVdc/dT) in the case of a small insertion amount of the core **1** (it is easy to receive the influence of the temperature coefficient of the DC voltage **Vdc** by nature) as well as the case of the large insertion amount of the core **1** (Although it is easy to receive the influence of the temperature coefficient of the AC voltage **Vac**, the 25 DC voltage **Vdc** is close to the AC voltage **Vac**). As a result, it is readily reduce the fluctuation width Δ(dV1/dT) of the temperature coefficient of the peak voltage **V1**.

Furthermore, the fluctuation width Δ(dV1/dT) of the temperature coefficient of the peak voltage **V1** can be reduced in the case that the value of 30 (dVdc/dT) is close to the value of (dVac/dT) at the maximum insertion amount

of the core **1**, in comparison with the case that the value of (dVdc/dT) is close to the value of (dVac/dT) at the minimum insertion amount of the core **1**.

Specifically, (dVdc/dT) and (dVac/dT) can be controlled by appropriately setting values of the temperature coefficients of the frequency **f**, alternating current **Iac**, and the direct current **Idc**, AC impedance **Zac**, and the DC resistance **Zdc**, according to the following methods.

First, the temperature coefficient of the DC resistance **Zdc** is determined by the selection of the winding material of the coil **2**. As the winding material, since a regular copper wire has a very large temperature coefficient, it is practical to use a nichrome wire, Manganin wire, or a copper-nickel alloy wire (GCN wire). In the case of using the copper-nickel alloy wire, volume resistivity and its temperature coefficient can be determined according to the compounding ratio between copper and nickel.

Next, a method of giving appropriate temperature coefficients to the direct current **Idc**, alternating current **Iac**, and the frequency **f** is explained. As shown in FIG. 10, the constant-current circuit **3** is composed of the oscillating circuit **3a** for providing the voltage Vdc' ± Vac', and a voltage-current conversion circuit **3b**. The oscillating circuit **3a** is, as shown in FIG. 11, comprises a comparator **CP1**, resistance **R3** connected between an output terminal and a noninverting input terminal of the comparator **CP1**, DC power source **E1** connected between the ground and an inverting input terminal of the comparator **CP1** to provide a voltage **Vcc/2**, resistance **R4** connected at its one end with the output terminal of the comparator **CP1**, operational amplifier **OP1** having an inverting input terminal connected to the opposite end of the resistance **R4** and a noninverting input terminal connected to the DC power source **E1**, capacitor **C2** connected between the output terminal and the inverting input terminal of the operational amplifier **OP1**, resistance **R2** connected between the output terminal of the operation amplifier **OP1** and the noninverting input terminal of the operation amplifier **OP1**, and a series circuit of resistances **R5**, **R6** connected between the output terminal of the operation

amplifier **OP1** and a control power source **Vcc**.

On the other hand, the voltage-current conversion circuit **3b** is composed of a resistance **R** connected at its one end with the control power source **Vcc**, and a PNP-type transistor **Q1** having an emitter connected to the opposite end of the resistance **R1**, base connected to the oscillating circuit **3a** and a collector connected to the coil **2**.

The signal processing circuit **4** uses a peak-hold type rectification circuit as a circuit for picking up the peak voltage **V1**. This circuit comprises a constant current source **I1** connected at its one end with the control power source **Vcc**, NPN-type transistor **Q2** having a collector connected to the opposite end of the constant current source **I1**, base connected to the collector, and an emitter connected to the coil **2**, NPN-type transistor **Q3** having a collector connected to the control power source **Vcc**, and a base connected to the base of the transistor **Q2**, and a parallel circuit of a capacitor **C1** connected between the ground and an emitter of the transistor **Q3**, and a constant current source **I2**. A voltage detected at both ends of the capacitor **C1** is a peak-hold voltage obtained by rectifying the voltage **Vs** detected at both ends of the coil **2**, i.e., the peak voltage **V1**, which is output as a displacement signal **Vout**.

To remove the influence of RF noises superimposed on the coil, it is preferred to dispose a low-pass filter at the input side of the signal processing circuit. In this case, it is possible to effectively remove the influence of the RF noises including harmonic components of a coil driving current and radiation noises from outside.

It is preferred that alternating current output from the constant-current circuit **3** is a triangular wave. In the above circuit, the output **Vosc** of the operation amplifier **OP1** is the triangular wave having an offset center of Vcc/2. The Dc voltage **Vdc'** and the AC voltage **Vac'** are determined by dividing the output **Vosc** with the resistances **R5**, **R6**. Such a triangular-wave oscillating circuit can realize a circuit stable to temperature changes by a simple configuration, as compared with a sine-wave oscillating circuit. When a

square-wave current is supplied to the coil **2**, a signal voltage occurs, which is hard to control due to di/dt of the square-wave current. Therefore, the square-wave oscillating circuit can not be used. In the case of using the triangular wave, it is possible to obtain the output voltage, to which the rotation

5 angle Θ of the core is reflected, as well as the case of using the sine wave.

In FIG. 11, the oscillating frequency **f** of the AC voltage **Vac'** is in proportion to **(R3/(C2 x R4 x R2))**, and the amplitude is in proportion to **(R2/R3)**. Therefore, by appropriately setting the temperature coefficients and the values of the capacitor **C2** and the resistances **R2** to **R6**, it is possible to

10 control the temperature coefficients and the values of the DC voltage **Vdc'** and the AC voltage **Vac'**. In particular, even when the constant-current circuit **3** is formed as a whole by a monolithic IC, the capacitor **C2** is often disposed outside. Therefore, the method of adjusting the temperature coefficient with the capacitor **C2** is effective.

15 In addition, when the constant-current circuit **3** is formed as a whole in a monolithic IC manner, appropriate temperature coefficients can be provided to the frequency **f**, alternating current **Iac** and the direct current **Idc** by setting resistance values of a part of the resistances **R1** to **R5** or all of them by digital trimming. In this case, even when the core **1**, coil **2** and the displacement

20 zone are changed, it is not needed to exchange the IC, and therefore versatility is high.

In the above, the digital trimming means carrying out a resistance adjustment by connecting a resistance to be adjusted to a parallel circuit of a resistance and a switching element in parallel, and then turning on/off the

25 switching element according to digital data. Specifically, in the case of carrying out the digital trimming, an optimum code of the digital data is determined, while electric characteristics being monitored, and then the determined optimum code is written in a ROM of the IC, or a fuse for data storage formed in the IC is burned out, so that the optimum code is given to the

30 IC, and the resistance in the IC is set to a value corresponding to this optimum

code. As the triangular-wave oscillating circuit, another circuit configuration other than FIG. 11 may be used.

In the voltage-current conversion circuit **3b** of FIG. 10, even when the temperature coefficient of the DC voltage **Vdc'** generated by the oscillating circuit **3a** is zero, the direct current **Idc** supplied to the coil **2** has a positive temperature coefficient due to the temperature characteristic of the voltage **Vbe** between the base and the emitter of the transistor **Q1**. In the case that the positive temperature coefficient of the direct current **Idc** is not desired, a voltage-current conversion circuit **3b'** of FIG. 12 may be used, which comprises an additional operation amplifier **OP2** having an inverting input terminal connected to the emitter of the transistor **Q1** of the voltage-current conversion circuit **3b** shown in FIG. 10, output terminal connected to the base of the transistor **Q1**, and a noninverting input terminal connected to the output of the oscillating circuit **3a**.

FIG. 13 shows a circuit configuration of a constant-current circuit **3'** different from the constant-current circuit **3** of FIG. 10. The constant-current circuit **3'** is composed of an alternating current supply circuit **Sac** and a direct current supply circuit **Sdc**. The alternating current supply circuit **Sac** is formed with a series circuit of a NPN-type transistor **Q4** and a PNP-type transistor **Q6**, AC power source **AC** connected to the midpoint between the transistors **Q4** and **Q6**, series circuit connected between the control power source **Vcc** and **Vee**, which is composed of a PNP-type transistor **Q8**, NPN-type transistor **Q5**, resistances **R7**, **R8**, PNP-type transistor **Q7** and a NPN-type transistor **Q10**, and a series circuit of a PNP-type transistor **Q9** and a NPN-type transistor **Q11**. The gates of the transistors **Q4** and **Q5** are connected to each other. The gates of the transistors **Q6** and **Q7** are connected to each other. The gates of the transistors **Q8** and **Q9** are connected to each other. The gates of the transistors **Q10** and **Q11** are connected to each other. In each of the transistors **Q8** and **Q11**, the base is short-circuited to the collector.

The direct current supply circuit **Sdc** is formed with a PNP-type transistor

Q12 having a collector connected to the midpoint between the transistors **Q9** and **Q11**, and an emitter connected to the control power source Vcc, PNP-type transistor **Q13** having an emitter connected to the control power supply Vcc, and a resistance **R9** connected between the ground and the collector of the

5 transistor **Q13**. The gates of the transistors **Q12**, **Q13** are connected to each other, and the base of the transistor **Q13** is short-circuited to the collector thereof.

The coil **2** is connected at its one end to the midpoint between the transistors **Q9** and **Q12**. Since the alternating current supply circuit **Sac** for

10 supplying the alternating current **Iac** is independent from the direct current supply circuit **Sdc** for supplying the direct current **Idc**, it is possible to simply control a ratio between the direct current **Idc** and the alternating current **Iac** and the temperature coefficient. Furthermore, they can be set by digital trimming.

15 When the signal processing circuit **4** comprises an amplifier having a reverse polarity temperature coefficient against the temperature coefficient of the peak voltage **V1** of the output voltage of the coil portion **A**, and the displacement signal **Vout** is output according to an output of this amplifier, the output of this amplifier depends on only the temperature compensated

20 displacement. Therefore, a temperature compensated displacement signal can be obtained by processing this output.

In addition, it is possible to control the temperature coefficients and the values of the DC resistance **Zdc** and the AC impedance **Zac** in addition to the constant-current circuit **3**. In place of the coil portion **A** explained in FIG. 1, a

25 coil portion **A** is used, which comprises a circuit element **5** composed of a DC resistance **Zdc'** and an AC impedance **Zac'** and connected in series to the coil **2**. At this time, the DC resistance **Zdc'** and the AC impedance **Zac'** of the circuit element **5** have no relation with the rotation angle Θ of the core **1**. Therefore, by appropriately selecting the temperature coefficients and the values of the DC

30 resistance **Zdc'** and the AC impedance **Zac'**, it is possible to control the

temperature coefficient and the peak value of the voltage detected at both ends of the coil portion **A**.

For example, when the circuit element **5** is a pure resistance, the AC impedance **Zac'** becomes **R** (resistance value). When the circuit element **5** is an inductance, it has both of the DC resistance **Zdc'** and the AC impedance **Zac'**. Furthermore, when a diode is used in the circuit element **5**, it is possible to give an influence only to the DC component **Vdc** of the voltage **Vs** detected at both ends of the coil **2**.

As explained above, by applying both of the alternating current **Iac** and the direct current **Idc** to the coil **2**, the fluctuation width $\Delta(dV1/dT)$ of the temperature coefficient of the signal voltage in the displacement zone (rotation angle) Θ can be remarkably reduced. Of course, as $\Delta(dZac/dT)$ is smaller, the fluctuation width $\Delta(dV1/dT)$ can be further reduced.

To reduce $\Delta(dZac/dT)$, it is desired that the core **1** is a magnetic material having a small temperature coefficient of magnetic permeability or electric resistivity. There is not a significant difference in the temperature coefficient of magnetic permeability among magnetic materials, for example, in the temperature range of -40 to +130°C. Therefore, it is particularly preferred to use the magnetic material having a small temperature coefficient of electric resistivity. For example, such a magnetic material comprises a nickel-chromium alloy, nickel-chromium-iron alloy, iron-chromium-aluminum alloy, copper-nickel alloy and Manganin. These metal materials are popularly used as heating wires, and available at a very low price. Therefore, when the core **1** is formed by cutting a heating wire to a required length, and bending the heating wire, it is possible to further reduce the fluctuation of the coil impedance with respect to temperature in the case that the core is inserted, and also minimize a loss of the material. Thus, the core **1** with excellent temperature characteristics can be produced at a low price.

As explained below, there is a case that $\Delta(dV1/dT)$ becomes larger than the $\Delta(dZac/dT)$ when the direct current **idc**, alternating current **Iac**, DC

resistance **Zdc**, and the AC resistance **Zac** and the temperature coefficients thereof are not appropriately set. For example, when the coil **2** has the DC resistance **Zdc** of 100 Ω (temperature coefficient 50 ppm/K), and the AC impedance **Zac** obtained by the above equation (3), wherein Z0=800 Ω,

5   Z'=-8Ω/deg, β0=346 ppm/K, and β'=-2.35 ppm/K/deg, and a direct current **Idc** of 0.2 mA and an alternating current **Iac** of 1.0 mA (these temperature coefficients are zero) are supplied to the coil **2**, FIG. 15 with plots corresponding to FIG. 8 is obtained. It shows that the Δ(dV1/dT) is larger than the Δ(dZac/dT). Thus, the Δ(dV1/dT) is not always reduced by simply supplying

10   the direct current **Idc**.

In the displacement detector of this embodiment, the displacement direction of the core is provided by the curved line. However, the same effects can be obtained in the case of using the displacement detector that the displacement direction is provided by a straight line.

15   (Second Embodiment)

In the present embodiment, a first temperature compensation method is explained, by which the change in impedance **Z** of the coil **2** with respect to temperature is not influenced by the displacement of the core **1** relative to the coil **2**, as an ideal condition that Δ(dZac/dT) becomes minimum. The

20   configuration of the displacement detector of this embodiment is the same as that of the first embodiment. Therefore, the same components are designated by the same reference numerals and duplicate explanation is omitted.

As the first temperature compensation method, a method of matching a change ratio of the impedance **Z** with respect to temperature in the case of not

25   inserting the core **1** in the coil **2** with the change ratio of the impedance **Z** with respect to temperature in the case of inserting the core **1** in the coil **2** is explained.

To control the impedance of the coil portion in the case of not inserting the core, thereby achieving that the change in impedance with respect to

30   temperature is not changed by the relative displacement of the core to the coil,

for example, it is preferred to determine each of the number of turns of the winding wire of the coil portion, winding pitch of the winding wire, and a frequency of the constant current input in the coil portion such that the temperature coefficient of the impedance of the coil portion is equal to the

5 temperature coefficient of the impedance of the coil portion resulting from the relative displacement of the core to the coil portion.

As shown in FIG. 16, the impedance Z of the coil 2 is equivalent to a series circuit of a resistance component Rs and an inductance component Ls. The inductance component Ls has a skin effect component. When the skin

10 thickness is sufficiently thin, and the frequency is constant, the skin effect is in proportion to the one-half power of volume resistivity ρ, and the temperature coefficient also receives the influence of the one-half power of volume resistivity ρ. FIG. 17 is a graph showing a fluctuation in resistance value of a copper wire brought by the skin effect, and provides a relationship between the

15 frequency and the resistance value of the copper wire. The curves $Y7$, $Y8$, $Y9$, and $Y10$ respectively correspond to the wire diameters of 0.32 mm, 0.16 mm, 0.10 mm and 0.07 mm. By the influence of the skin effect, a degree of change in the resistance depends on the frequency and the wire diameter of the coil.

In addition, the temperature coefficient of the resistance component Rs

20 largely depends on the temperature coefficient of volume resistivity ρ of the winding material, and the resistance component Rs also receives the influence of a proximity effect. FIG. 18 is a graph showing a fluctuation in resistance value of the copper wire brought by the proximity effect. The curves $Y1$ and $Y12$ respectively correspond to combinations of the wire diameter and the

25 number of turn, 0.16 mm, 40T and 0.07 mm, 60T. The proximity effect is a phenomenon that when the winding wire of the coil is wound at a narrow winding pitch, electric current does not uniformly flow in the winding wire. As the winding pitch is narrower, the influence increases. The influence also depends on the wire diameter. Since the proximity-effect component has a

30 dependency on volume resistivity ρ to the power of minus one, the temperature

coefficient also receives the influence of the volume resistivity ρ to the power of minus one.

That is, when the wire diameter is thick or the frequency is high, the temperature coefficient of the impedance Z at the time of not inserting the core 1 is reduced by the skin effect and the proximity effect. Therefore, the balance among the DC resistance component, the skin-effect component and the proximity-effect component under the displacement condition of not inserting the core 1 can be controlled to reduce the temperature coefficient of the impedance Z of the coil 2 by appropriately setting the volume resistivity ρ of the winding wire, wire diameter, the number of turn, winding pitch and the frequency. Therefore, it is possible to solve a problem that the temperature coefficient changes in response to the displacement amount.

As the winding material, since copper has a very large temperature coefficient of the volume resistivity ρ, it is desired to select a material having a smaller temperature coefficient of the volume resistivity ρ than copper. Specifically, nichrome, Manganin, or a copper-nickel alloy is preferably used as the winding material of the coil 2. In particular, it is preferred to use the copper-nickel alloy because the volume resistivity ρ can be controlled by changing the compounding ratio of the alloy.

Next, a second temperature compensation method of matching a change ratio of the impedance Z with respect to temperature in the case of inserting the core 1 in the coil 2 with the change ratio of the impedance Z with respect to temperature in the case of not inserting the core 1 in the coil 2 is explained.

To control the impedance of the coil portion in the case of inserting the core, thereby achieving that the change in impedance Z with respect to temperature is not changed by the relative displacement of the core to the coil portion, for example, it is preferred to form the core by a material selected such that the temperature coefficient of the impedance of the coil portion is equal to the temperature coefficient of the impedance of the coil portion resulting from the relative displacement of the core to the coil portion. Alternatively, it is

preferred to perform a surface treatment to the core such that the temperature coefficient of the impedance of the coil is equal to the temperature coefficient of the impedance of the coil portion resulting from the relative displacement of the core to the coil portion.

5   An increase in impedance Z of the coil 2 caused by inserting the core 1 depends on volume resistivity ρ and magnetic permeability μ of the core 1. Therefore, since the temperature coefficient is also associated with the temperature coefficients of volume resistivity ρ and magnetic permeability μ of the core 1, it is preferred to adequately select the core 1 having the volume

10   resistivity ρ and the magnetic permeability μ such that the temperature coefficient in the presence of the core 1 in the coil 2 matches with the temperature coefficient in the absence of the core 1 in the coil 2. Alternatively, a surface treatment may be performed such that the surface of the core 1 is of suitable volume resistivity ρ and magnetic permeability μ.

15   Generally, the ambient temperature, at which the displacement detector is used, is 120 to 130 °C at the highest. Curie Temperature of the core 1 is sufficiently higher than the ambient temperature. Although the magnetic permeability μ sharply reduces at the vicinity of Curie temperature, it seldom changes in the temperature range where the displacement detector is used.

20   Therefore, when forming at least a surface of the core 1 with a material having a small change in volume resistivity ρ that is another factor affecting the increase in impedance Z of the coil 2, it is possible to reduce the temperature coefficient of the impedance Z, and thereby minimizing the fluctuation of the impedance Z of the coil 2 with respect to temperature.

25   For instance, in the displacement detector of the first embodiment for carrying out position detection according to the change in impedance of the coil 2, a primary component of this impedance is inductance. When a magnetic field developed in an axial direction of the coil 2 by flowing the constant current in the coil 2, a ring-like current (so-called eddy current) flows in the core 1 to

30   cancel the magnetic field developed in the axial direction. This ring-like

current has an action of lowering the inductance of the coil **2**. The magnitude of the ring-like current depends on the volume resistivity of the core **1**, as well as the magnitude and the frequency of the magnetic field applied (In the case of using a constant current and a fixed frequency, there is no fluctuation.). That

5 is, as the volume resistivity of the core **1** increases, the ring-like current becomes smaller, so that the action of lowering the inductance reduces. Therefore, when the volume resistivity of the core **1** has a temperature characteristic, the inductance also has a temperature characteristic. Thus, the temperature characteristic of the inductance greatly affects the temperature

10 characteristic of the impedance.

When the coil **2** is actually used as an impedance factor, it is often driven by the supply of an electric current with a frequency of several ten KHz to several hundred KHz. In this case, the magnetic field developed at the frequency by the coil **2** does not reach the interior of the coil **1**, and gathers in

15 the vicinity its surface.

Therefore, it is preferred that at least the surface of the core **1** is of one of a nickel-chromium alloy, nickel-chromium-iron alloy, iron-chromium-aluminum alloy, copper-nickel alloy and Manganin, each of which is a material having a small volume resistivity ρ. In this case, it is possible to reduce the

20 fluctuation of impedance with respect to temperature of the coil under the condition that the core is inserted into coil. These materials are called as electric heating material. It has a small temperature coefficient of resistance. In addition, since iron or nickel is a magnetic material, their alloys often have magnetism. Therefore, the impedance change can be considerably reduced.

25 However, if the core **1** is configured in a bulk shape by the material having a small volume resistivity, a further improved temperature characteristic can be obtained. When using the electric heating material such as the nickel-chromium alloy, nickel-chromium-iron alloy, iron-chromium-aluminum alloy, copper-nickel alloy and Manganin, and forming the bulk shape of the core **1** by

30 punching a flat sheet of those materials, the production cost becomes expensive

due to the material loss. However, by cutting a marketed wire of the electric heating material, which is easy to get, to a required length, and then performing a bending process (or a drawing process), the core can be economically produced without the occurrence of useless industrial wastes.

5   A combination of the first and second temperature compensation methods may be adopted to effectively perform the temperature compensation.

(Third Embodiment)

       The displacement detector of the first embodiment intends to minimize the fluctuation width (displacement dependency of temperature coefficient) of the

10   temperature coefficient of the displacement signal **Vout** resulting from the relative displacement of the core **1** to the coil **2** according to the ratio between the AC voltage **Vac** and the DC voltage **Vdc** generated at both ends of the coil **2** when the direct current **Idc** and the alternating current **Iac** are supplied to the coil **2**. In addition, as shown in FIG. 19, the signal processing circuit **4** is, for

15   example, composed of the peak-hold circuit **4a**, temperature compensation circuit **4c**, nonlinearity compensation circuit **4e**, and the amplifying circuit **4d**. The peak-hold circuit **4a** extracts the peak value **V1** of the voltage **Vs** detected at the both ends of the coil **2**. The temperature compensating circuit **4c** performs a temperature compensation to the peak value **V1** with the

20   temperature coefficient having the reverse polarity against the temperature coefficient of the peak value **V1**. The nonlinearity compensation circuit **4e** compensates the linearity to the relative displacement of the core **1** to the coil **2**. The amplifying circuit **4d** carries out a signal amplification to output the displacement signal **Vout**.

25   On the contrary, in the displacement detector of this embodiment, as shown in FIG. 20, the signal processing circuit **4** is composed of the peak-hold circuit **4a**, a level shift circuit **4b**, the temperature compensating circuit **4c**, and the amplifying circuit **4d**. The peak-hold circuit **4a** extracts the peak value **V1** of the voltage **Vs** detected at the both ends of the coil **2**. The level shift circuit

30   **4b** adds a level shift value **Vsh** to the peak value **V1** to provide a signal **V2**.

The temperature compensating circuit **4c** performs a temperature compensation to the signal **V2** with a temperature coefficient having the reverse polarity against the temperature coefficient of the signal **V2** to provide a signal **V3**. The amplifying circuit **4d** carries out an amplification of the signal **V3** to

5 output a displacement signal **Vout**.

To remove the influence of RF noises superimposed on the coil, it is preferred to dispose a low-pass filter at the input side of the signal processing circuit. Though the RF noises include harmonic components of a coil driving current and radiation noises from outside, it is effective to remove these

10 influences.

As described above, the displacement detector of the present embodiment is characterized by extracting the characteristic value **(V1)** from the output voltage of the coil by the peak-hold circuit **4a**, adding the level shift voltage **(Vsh)** to this characteristic value by the level shift circuit, so that a fluctuation

15 width of temperature coefficient of a total of the characteristic value **(V1)** and the level shift voltage **(Vsh)** in the movable range of the core is smaller than the fluctuation width of temperature coefficient of the characteristic value **(V1)** in the movable range.

Thus, since the level shift value **Vsh** is added to the peak value **V1** by the

20 level shift circuit **4b**, the direct current **Idc** supplied to the coil **2** may be zero or a small value. Therefore, it is effective when there is a limitation in electric current consumption (In FIG. 3, the direct current Idc = 0). On the contrary, in the first embodiment, since a large value of Idc/Iac is needed to minimize the displacement dependency of the peak value **V1**, there is a fear of increasing the

25 electric current consumption.

The peak value **V1** is represented by the above equation (2), and on the other hand, the signal V2 is represented by the following equation:

$$V2 = (Idc * Zdc + Vsh) + Iac * Zac \quad \cdots (4)$$

wherein $(Idc * Zdc + Vsh)$ corresponds to the DC voltage **Vdc**. An appropriate

30 setting of the temperature coefficient or the magnitude (absolute value) of the

level shift value **Vsh** is equivalent to the appropriate setting of the temperature coefficient or the ratio between the direct current **Idc** and the alternating current **Iac**, as in the case of the first embodiment. In addition, an appropriate setting of any one of the temperature coefficients and the values of the AC
5   impedance **Zac**, DC resistance **Zdc**, alternating current **Iac** and the direct current **Idc**, other than the level shift value **Vsh** is equivalent to the appropriate setting of the temperature coefficient and the ratio between the DC voltage **Vdc** and the AC voltage **Vac** of the signal **V2**. Therefore, it is possible to minimize the fluctuation width of the temperature coefficient of the signal **V2**.

10   The displacement detector of this embodiment has the same configuration as that in the first embodiment. However, in the present embodiment, as shown in FIG. 21, as the rotation angle Θ of the movable block **13** changes from 0° toward 90°, an insertion amount of the core **1** into the coil **2** increases. FIG. 22 shows a temperature coefficient of the AC impedance **Zac** of the coil **2**
15   relative to the rotation angle Θ. The AC impedance **Zac** has a displacement dependency. That is, as the rotation angle Θ is larger, the insertion amount of the core **1** into the coil **2** increases, so that the displacement dependency increases (In the range of the rotation angle Θ = 0 to 100°, there is a difference of about 470 ppm/°C). A measured frequency of the AC impedance **Zac** is 70
20   KHz. The DC resistance **Zdc** is 58 Ω (25°C). The temperature coefficient of the DC resistance **Zdc** is 3900 ppm/°C.

        FIG. 23 shows a temperature coefficient of the peak value **V1** extracted under the device configuration of FIG. 19. By changing the value of **Idc/Iac** under a condition of the alternating current **Iac**=1 mA, it is possible to control
25   the displacement dependency of the temperature coefficient of the peak value **V1**. When the value of **Idc/Iac** is in the vicinity of 1.0, the displacement dependency of the temperature coefficient of the peak value **V1** can be minimized. For simplicity, it is assumed in this case that there is no change in frequency, the alternative current **Iac**, and the direct current **Idc** with respect
30   to temperature (and so forth).

On the other hand, FIG. 24 shows a temperature coefficient of the signal **V2** under the condition of changing the level shift value **Vsh** from 0 mV to 200 mV by use of the device configuration of FIG. 20. The direct current **Idc** is zero, and the temperature coefficient **h** of the level shift value **Vsh** is 3000 ppm/°C.

5   In this case, it is possible to control the displacement dependency of the temperature coefficient of the signal **V2** by changing the level shit value **Vsh**. When the value Vsh is in the vicinity of 100 mV, the displacement dependency of the temperature coefficient of the signal **V2** can be minimized. As a result, the same effects as the case of FIG. 19 can be obtained.

10   In addition, FIG. 25 is a temperature coefficient of the signal **V2** under the condition of changing the temperature coefficient **h** of the level shift value **Vsh** from 0 ppm/°C to 5000 ppm/°C by use of the device configuration of FIG. 20. The direct current **Idc** is zero, and the level shift value **Vsh** is 100 mV. In this case, it is possible to control the displacement dependency of the temperature coefficient of the signal **V2** by changing the temperature coefficient **h**. When

15   the temperature coefficient **h** is in the vicinity of 2000 ppm/°C, the displacement dependency of the temperature coefficient of the signal **V2** can be minimized. As a result, the same effects as the case of FIG. 19 can be obtained.

20   To the thus obtained signal **V2**, a temperature compensation having no displacement dependency is performed by the temperature compensation circuit **4c** (for example, it is approximately –1200 ppm/°C in FIG. 23, approximately –1450 ppm/°C in FIG. 24, and approximately –1300 ppm/°C in FIG. 25), thereby obtaining the signal **V3** that do not depend on the ambient

25   temperature, and is substantially equal to the signal **V2** for the displacement at room temperature. Then, a required amplification is performed to the signal **V3** by the amplifying circuit **4d** to output the displacement signal **Vout** (when the amplification is not needed, the signal **V3** is output as the displacement signal **Vout**). As the temperature compensation circuit 4c, it is not limited to

30   perform a primary compensation to temperature. For example, it may be

provided by a circuit for performing a secondary compensation or another compensation represented by a nonlinear equation. Similarly, the amplifying circuit **4d** may be provided by a circuit with an amplification degree represented by a nonlinear equation for the signal **V3**.

5   As shown in FIG. 26, even when the level shift circuit **4b** is connected between the coil **2** and the peak-hold circuit **4a**, the signal **V2** is represented by the equation (4). Therefore, the same effects can be obtained.

In the present embodiment, when circuit constants or coefficients for the amplification, the temperature coefficient of the temperature compensation, in

10   addition to the level shift value **Vsh** and the temperature coefficient **h** of the level shift value **Vsh** can be stored in, for example, an EEPROM, and they can be set appropriate values to individual products, it is possible to minimize characteristic fluctuations resulting from a temperature change without being affected by an individual difference of the coil **2** or the signal processing circuit

15   **4**.

Next, calibrations of the level shift value **Vsh** and its temperature coefficient are explained below, which are individually performed at the time of manufacturing the displacement detector.

As shown in FIG. 24, to minimize the displacement dependency of the

20   temperature characteristic by controlling the level shift value **Vsh**, the temperature characteristics of the peak value **V1** and the signal **V2** for each of displacements (rotations) under a temperature cycle are measured to determine an optimum level shift value **Vsh**, and then a coefficient (circuit constant) of the amplifying circuit **4d** is determined according to the level shift value **Vsh**.

25   Thus, since the displacement signal **Vout** is obtained after the setting of the coefficient of the amplifying circuit **4d**, it is needed to perform the temperature cycle again to check the temperature characteristic of the displacement signal **Vout**.

On the other hand, as shown in FIG, 25, to minimize the displacement

30   dependency of the temperature characteristic by controlling the temperature

coefficient **h** of the level shift value **Vsh**, the coefficient of the amplifying circuit **4d** can be firstly determined at room temperature (the gain of the temperature compensation circuit **4c** is 1). Then, an optimum temperature coefficient **h** or the temperature coefficient of the temperature compensation circuit **4c** is

5   determined by measuring the temperature characteristics of the peak value **V1** and the signal **V2** for each of the displacements (rotations) under the temperature cycle. In this case, since the displacement signal **Vout** can be checked under this temperature cycle, it is not needed to repeat the temperature cycle. Thus, the calibration can be more simply performed by

10   controlling the temperature coefficient **h** of the level shift value **Vsh** in comparison with the case of controlling the level shift value **Vsh**.

As in the case of the first embodiment, when the bias current is supplied to the coil **2**, the calibration can be more simply performed by controlling the temperature coefficient of the frequency, alternating current **Iac**, or the direct

15   current **Idc**, as compared with the case of controlling the value of **Idc/Iac**, as shown in FIG. 23.

In the above explanation, a signal processing of the peak value **V1** of the voltage detected at both ends of the coil **2** as the original signal is performed. Alternatively, a signal processing of a bottom voltage of the voltage detected at

20   both ends of the coil **2** as the original signal may be performed. In this case, the following equations are used in place of the equations (2) and (4).

$$V1 = Vdc + Vac = Idc * Zdc - Iac * Zac \quad \cdots (5)$$

$$V2 = (Idc * Zdc + Vsh) - Iac * Zac \quad \cdots (6)$$

In this case, by appropriately setting the temperature coefficient **h** of the

25   level shift value **Vsh** and the level shift value **Vsh** (at least one of them is set to a negative value), the same effects as the above can be obtained. Alternatively, by using an effective value or a peak-to-peak voltage of the voltage detected at both ends of the coil **2** as the original signal, and performing a level shift to the original signal, the same effects as the above can be obtained.

30   Thus, according to the second embodiment, it is not needed to use the

temperature coefficient of the DC resistance **Zdc** of the coil **2**. Therefore, it is enough to extract only the AC voltage **Vac** from the voltage detected at both ends of the coil **2**, and give a DC voltage (level shift value **Vsh**) by the level shift circuit **4b**. This provides a greater degree of freedom of circuit design.

5 (Fourth Embodiment)

A displacement detector of the present embodiment comprises, as shown in FIG. 27, an A/D conversion circuit **4f** connected to a peak-hold circuit **4a**, and a digital operation block **4g** connected to the A/D conversion circuit **4f** and composed of a level shift portion **41**, temperature compensating portion **42** and

10 an amplifying portion **43**. A peak value **V1** of the voltage detected at both ends of the coil **2** is converted into a digital signal **DV1** by the A/D conversion circuit **4f**. Then, as an digital signal operation performed in the digital operation block **4g**, a required digital quantity is added by the level shift portion **41** to obtain a level shifted digital signal **DV2**. In the temperature compensating

15 portion **42**, an operation for carrying out a temperature compensation is performed to the digital signal **DV2**. In addition, the amplifying portion **43** amplifies a digital output signal of the temperature compensating portion **42** to output the displacement signal **Vout** that is a digital signal.

Thus, when the signal is digitalized, the coefficient for amplifying,

20 temperature coefficient for the temperature compensation, temperature coefficient and digital quantity for the level shift can be determined from calculations by measuring only temperature characteristic of the peak value **V1** in one temperature cycle. In addition, there is an advantage that the temperature characteristic of the output displacement signal **Vout** can be

25 checked by calculation (an error between the actual output and the calculated output is smaller than quantization error). Moreover, it is possible to obtain an analog signal output by D/A converting the digital operation result.

(Fifth Embodiment)

In this embodiment, a method of improving the linearity of output is

30 explained. The configuration of the displacement detector of the present

embodiment is substantially the same as that in any one of the first to fourth embodiments. Therefore, the same components are designated by the same reference numerals and the duplicate explanation is omitted.

As a first method of improving the linearity of output, an appropriate material for the core **1** is selected, and a frequency **f** of the alternating current **Iac** is appropriately determined. The inventors of this invention carried out experiments concerning the linearity of AC impedance **Zac** by changing the material of the coil **2** introduced in the first embodiment. FIG. 28 is a list of metal materials used of soft magnetic iron, Permalloy, electromagnetic stainless steel, SUS430, iron chrome, and corresponding estimated characteristics, i.e., resistivity. In FIG. 28, "electromagnetic stainless steel" is a metal containing Si, Mn, P, Ni and Ti in addition to 11% of Cr, and used for electromagnetic valves and relay yokes. To allow each of the metal materials to exhibit the magnetic characteristic, a heat treatment was performed under a condition peculiar to the respective metal material. Shapes of the metal materials are identical to each other.

FIGS. 29A to 29E show experimental results of the linearity of AC impedance **Zac** of the metal materials in each of frequencies **f**, 10KHz, 30KHz, 50KHz, 70KHz and 90KHz of the alternating current **Iac**. From these results, it can be understood that the magnetic stainless steel (electromagnetic stainless steel) exhibits good linearity in comparison with the soft magnetic iron and pure iron. In particular, since SUS430 (18Cr ferritic stainless steel) is inexpensive and exhibits corrosive resistance as well as good linearity to both of the angle span and the frequency, it is preferably used as the core material of the displacement detector. It is conceived that these linearities are determined by the balance between resistivity and magnetic permeability and the frequency characteristic. For example, since iron chrome has a desirable linearity when the frequency is larger than 50 KHz, it becomes an appropriate core material having an advantage of a change ratio of resistivity with respect to temperature by performing a countermeasure to corrosion resistance.

As a second improving method, countermeasures for minimizing the "end effect" indicated as the problem in the conventional art are performed. For example, it is preferred that magnetic flux easily passes through a portion extending over a required length from an end of the core than the remaining portion, or the portion extending over the required length from the core end has a larger diameter than the remaining portion. Alternatively, the portion extending over the required length from the core end may be made of a material having a higher magnetic permeability than the remaining portion. In these cases, the "end effect" is reduced, so that the linearity of output can be maintained over a wider zone.

FIGS. 30A and 30B show that a contribution of a lead end part **1a** or **1b** of the core **1** to the AC impedance **Zac** is increased by appropriately determining the shape of the core **1**. In FIG. 30, the lead end part **1a** of the core **1** is formed in a rectangular shape to be thicker than the remaining portion of the core **1**. In FIG. 30B, the lead end portion **1b** of the core **1** has a wedge shape formed to be thicker than the remaining portion of the core **1**. In both cases, since the lead end portion (**1a** or **1b**) is thicker than the remaining portion of the core, it is possible to increase an amount of interlinkage magnetic flux among the pitches of the wound wire, thereby further contributing to an increase in inductance. In addition, when the core **1** is formed by etching or metal injection molding, an increase in production cost can be prevented.

FIG. 30C shows that the amount interlinkage magnetic flux at a lead end part **1C** of the core **1** can be increased by forming the lead end part **1C** with a material having a higher magnetic permeability than the core main body, thereby contributing to the increase in inductance. In the cases of FIGS. 30A and 30B where the remaining part must be thinner than the lead end part, a decrease in sensitivity may occur. However, in the case of FIG. 30C, such a decrease in sensitivity does not occur. In addition, since the core has a constant thickness, it becomes mechanically stable, and can be readily formed by a combination of two parts.

In addition, it is also preferred to perform a surface treatment to the portion extending over the required length from the core end with the material having a higher magnetic permeability than the remaining portion, or form a surface of the portion extending over the required length from the core end with

5   a Permalloy-plated electromagnetic stainless steel. In addition, chamfering may be performed to edges of the core end.

FIG. 30D shows a case that a lead end part **1d** of the core is surface-treated (plated) with the material having a high magnetic permeability. This further improves the case of FIG. 30C in the aspects of reducing time and

10   labor for production and facilitating positioning. In addition, since the core thickness can be kept constant, the core becomes mechanically stable, and a curved coil can be readily formed. In place of plating, for example, a foil material having the high magnetic permeability may be adhered.

A displacement detector shown in FIG. 31 comprises a coil **2** produced by

15   winding a wire on a hollow bobbin **15**, and a core **1** extending in the winding direction X of the coil **2** to such that the core **1** can be inserted in the hollow portion of the bobbin **15**. A constant-current circuit and a signal processing circuit (not shown) are formed in a same manner as any one of the first to fourth embodiments. In this embodiment, the core **1** is configured in a

20   conventional shape, and the winding wire is wound such that the coil end portions are thicker (namely, the number of winding layers is greater) than the remaining portion. Therefore, even when only the lead end part of the core **1** is inserted, the magnetic flux developed by the greater number of winding layers can be interlinked to increase the inductance.

25   In addition, to prevent the occurrence of an accidental friction between the core **1** and an inner surface of the bobbin of the coil **2**, it is preferred to perform chamfering to the lead end part of the core **1**, or a round-off treatment for removing edges, as shown in FIGS. 32A to 32E. In these cases, a deterioration of the linearity can be prevented without such a friction. In FIGS. 32A to 32E,

30   the chamfering or the round-off treatment is performed to the lead end parts of

the cores **1** shown in FIGS. 30A to 30D.

In FIG. 4 showing the cross sections of the core **1** and the coil **2**, a coating **11** of a nonmagnetic material such as copper is formed on the inner surface of the curved bobbin **10**, in which the core **1** can be inserted, to prevent the friction between the core **1** and the coil **2**. In the case of using a metal material or a conductive material as the coating **11**, it is needed that the material does not form a closed loop in the cross section. In place of the metal deposition, a part of the side surface in the through hole of the bobbin may be formed by a sheet metal member. Alternatively, a material having slidability and wear resistance such as fluorine coating may be used to obtain the same effects. In these cases, since a foil or a linear member (particularly, amorphous) is used for the core **1**, and the core is slidable along the side surface in the through hole of the curved bobbin **10**, there are effects of thinning the displacement detector or reducing the diameter as well as improving the linearity of output.

In the case of using a Permalloy-plated electromagnetic stainless steel, there are effects that the a well-balanced magnetic permeability between the core end and the remaining portion and excellent corrosion resistance are obtained. Moreover, when the coil **2** is formed by a spring coil to be inserted in the curved bobbin **10**, it is possible to readily obtain a uniform winding pitch.

In addition, as shown in FIG. 2, the housing has a curvature correcting member **12** for restoring a reduced curvature of the curved bobbin deformed by a winding tension of the coil **2** into its original state. The curvature correcting member **12** is formed with a groove having substantially the same curvature as the coil **2**. When the coil **2** is inserted into the groove of the curvature correcting member **12**, the curvature correcting member **12** makes contact with an inside radius portion and a bottom side of the coil **2** to correct the reduction in curvature of the curved bobbin **10**. The curvature correcting member **12** may correct the change in curvature of the coil by making contact with at least a part of the inside radius portion of the coil **2**. In FIG. 2, the curvature

correcting member **12** is separately formed from the housing **14**. Alternatively, a similar groove may be formed in the housing **14** itself.

The formation of such a curvature correcting member **12** presents another advantage described below. That is, in the coil **2** not having such a structure, it is needed that retaining/fixing members **16** are provided outside in the vicinity of a flange and at the opposite ends of the coil **2**, as shown in FIG. 33. In the presence of the retaining/fixing members, a stroke (mechanical displacement amount) of the core **2** is restricted. However, in the case of FIG. 2 that the retaining/fixing member is not formed, a prolonged stroke of the core **1** is available. Alternatively, in place of the prolonged stroke, an angle range of the winding portion of the curved bobbin **10** may be extended to improve the linearity of output.

(Sixth Embodiment)

A displacement detector of the present embodiment shown in FIGS. 34 to 37 is formed according to an idea of a failsafe system and in consideration of its use in automobiles (e.g., a position sensor for detecting the position of an acceleration pedal). In this view, the displacement detector has a structure obtained by doubling the coil portion of the displacement detector shown in FIG. 2 or 3. In FIGS. 34 and 35, the displacement detector comprises a pair of coils **2a**, **2b** curved at the same curvature, and a pair of core **1a**, **1b** curved at the same curvature such that each of the cores can be inserted in the corresponding coil (**2a**, **2b**) by rotating a movable block **13** about a rotation axis. These two coils **1a**, **1b** are laid one over the other in the direction of the rotation axis. In comparison with the case of FIG. 44 where two coils are displaced on the same plane, it is possible to increase the opening angle of the winding portion of the coils **2a**, **2b**, and a mechanical rotation angle of the movable block **13**. As a result, it is possible to provide a wide range of the rotation angle Θ, in which the linearity of impedance **Z** of each of the coils **2a**, **2b** is good. Moreover, since these coils **2a**, **2b** can be formed to have the same characteristic, there are advantages in easiness of wire winding and cost

performance.

A displacement detector shown in FIGS. 36 and 37 comprises a coil **2a** curved at a small curvature, coil **2b** curved at a large curvature, and a pair of cores **1a, 1b** curved at small and large curvatures such that each of the cores

5 can be inserted in the corresponding coil (**2a, 2b**) by rotating a movable block **13** about a rotation axis. The cores **2a, 2b** are disposed on the same plane to extend over the same range of the rotation angle Θ with respect to the rotation axis of the cores **1a, 1b** and. Therefore, as in the case of the displacement detector shown in FIGS. 34 and 35, it is possible to increase the opening angle

10 of the winding portion of the coils **2a, 2b**, and the mechanical rotation angle of the movable block **13**. As a result, a wide range of the rotation angle Θ is obtained, in which the linearity of impedance **Z** of each of the coils **2a, 2b** is good. Moreover, there is another advantage of thinning the displacement detector.

15 By integrally molding the coils **2a, 2b** wound on the curved bobbins **10a, 10b** with a resin material **17**, it is possible to prevent disconnection of the wire at the time of assembling, or receiving vibration/impact. In addition, since there is no displacement in positional relation between the coils **2a, 2b** at the time of assembling, it is possible to minimize variations in output between two

20 detecting sections. Moreover, positioning of these two coil portions integrally molded and the movable block **13** becomes easy, and the time required for assembling is shortened. By performing the resin molding under a condition that there is no deformation of the curved bobbins **10a, 10b**, the formation of a specific member for correcting the deformations of the curved bobbins can be

25 omitted. Furthermore, the cores **1a, 1b** may be integrally molded with the resin material to be inserted in the coils. There are advantages that positioning is enhanced at the time of assembling and variations in output between the two coil portions can be prevented.

(Seventh Embodiment)

30 The configuration of a displacement detector of the present embodiment is

substantially the same as that in any one of the first to sixth embodiments. Therefore, the same components are designated by the same reference numerals and the duplicate explanation is omitted.

In the present embodiment, the displacement signal **Vout** output from the signal processing circuit **4** is explained. When a system (EUC) of processing a signal output from the signal processing circuit is a digital circuit, and the displacement signal **Vout** is an analog signal, an error and a response delay may be caused by repeating redundant A/D conversion or D/A conversion. However, when the displacement signal **Vout** is a digital signal, these problems do not occur. In addition, it is possible to reduce the influence of external noises on the signal transmission. Therefore, in the present embodiment, the displacement signal output from the signal processing circuit **4** is the digital signal. The signal processing circuit **4** has a signal correcting circuit composed of an A/D conversion circuit for converting the peak value **V1** of the output voltage of the coil portion **A** into the digital signal, and a correcting circuit for performing digital trimming to the digital signal.

It is preferred that the displacement signal output from the signal processing circuit is composed of an output initiate signal, and one of a pulse signal provided after the elapse of a duration depending on position data from the output of the output initiate signal, pulse signal having a duty ratio that depends on the position data provided in succession to the output initiate signal, pulse signal having a pulse width that depends on the position data provided in succession to the output initiate signal, and a pulse signal(s), the number of which depends on the position data provided in succession to the output initiate signal.

FIGS. 38A and 38B show a first example of the displacement signal **Vout** provided from the signal processing circuit **4**. The displacement signal **Vout** is composed of an output initiate signal having a width **T1** corresponding to three pulse widths of a reference pulse **Vr**, and a pulse signal provided after the elapse of a duration **T2** from the output of the output initiate signal. At the

ECU side, by measuring the pulse width **T1** of the output initiate signal and the duration **T2** with a timer, a relative position of the core **1** to the coil **2** can be determined.

FIGS. 39A and 39B show a second example of the displacement signal **Vout** provided from the signal processing circuit **4**. The displacement signal **Vout** is composed of an output initiate signal having a width corresponding to three pulse widths of the reference pulse **Vr**, and pulse signals, the number of which depends on the position data provided in succession to the output initiate signal. At the ECU side, by counting the number of the pulse signals with a counter, a relative position of the core **1** to the coil **2** can be determined. FIGS. 40A and 40B show a third example of the displacement signal **Vout** provided from the signal processing circuit **4**. The displacement signal **Vout** is composed of a pulse signal having a duty ratio depending on the position data. ON/OFF times of the duty ratio are respectively determined according to the number of pulses of the reference pulse **Vr**. At the ECU side, by measuring the period and the pulse width with a timer, a relative position of the core **1** to the coil **2** can be determined.

Securing a required bit number of digital output leads to an increase in the number of wirings between the displacement detector and the ECU. However, according to above configurations, only one signal line is needed. The displacement signal **Vout** may be composed of a pulse signal having a pulse width that depends on the position data. If there is no limitation in the number of signal lines, the displacement signal **Vout** may be composed of a digital signal with a bit number satisfying a resolution needed for position detection. In this case, it is possible to perform reading in a real-time manner by the ECU, thereby facilitating the processing.

(Eighth Embodiment)

A cross-sectional structure and a circuit configuration of a displacement detector of the present embodiment are shown in FIGS. 41 and 42, respectively. The configuration of each of signal processing circuits **4a**, **4b** is the same as

that in any one of the first, third and fourth embodiments.

The displacement detector of this embodiment has a double-layered structure of sensor coil portions according to the failsafe system and in consideration of its use in automobiles. The displacement detector comprises a pair of coils **2a**, **2b** each obtained by winding a wire on a hollow bobbin **15** and disposed to be opposed to each other in the winding-axis direction, core **1** that can be inserted in hollow portions of the bobbins **15** and displaced in the winding-axis direction X of the coils **2a**, **2b**, constant-current circuit **3** for respectively outputting constant currents **Ida**, **Idb** to the coils **2a**, **2b**, signal processing circuit **4a** for converting a peak value of a voltage detected at both ends of the coil **2a** determined by the constant current **Ida** provided from the constant-current circuit **3** and impedance **Za** of the coil **2a** into a displacement signal indicative of position data between the core **1** and the coil **2a**, and a signal processing circuit **4b** for converting a peak value of a voltage detected at both ends of the coil **2b** determined by the constant current **Idb** provided from the constant-current circuit **3** and impedance **Zb** of the coil **2b** into a displacement signal indicative of position data between the core **1** and the coil **2b**.

In the present embodiment, the two coils **2a**, **2b** commonly use the core **1**, which is attached to a structural member (not shown). In addition, the same constant-current circuit **3** respectively provides the constant currents **Ida**, **Idb** each having a required frequency and a required amplitude to the coils **2a**, **2b**. Therefore, it is possible to reduce an increase in cost caused by the formation of the double-layered structure of the coil portions.

In addition, an integrated circuit (IC) section is the most expensive part. Therefore, when active circuit sections of the constant-current circuit **3** and the signal processing circuits **4a**, **4b** are composed of a monolithic integrated circuit, it is possible to further reduce the increase in cost caused by the formation of the double-layered structure of the coil portions.

Hereinafter, explained are some of examples as to how to specifically use

the displacement detector according to the first to eighth embodiments. First, in the case of using the detector as a position sensor for detecting the position of an acceleration pedal in automobiles, curved bobbins having the same curvature can be arranged on the same plane because the detection angle is

5   relatively narrow, i.e., about 30°. Therefore, impedances of the coils are in a complementary relation. In addition, since the detector is disposed in a driver room of the automobile, an upper limit of the operation temperature of the detector is not so high. Furthermore, since there is a sufficiently large stroke with respect to the detection angle, an intermediate portion of the stroke having

10   good linearity of output can be used without largely modifying the material and the shape of the core.

    Next, in the case of using the detector as a throttle position sensor, a large detection angle of about 90° or more, and a large mechanical stroke are needed. For this viewpoint, it is preferred to use the double-layered structure of the

15   curved bobbins shown in FIGS. 34 and 35, or the structure characterized by the curved bobbins having different curvatures and arranged on the same plane so as to have the same range of rotation angle, as shown in FIGS. 36 and 37. In addition, since there is a limitation in the mechanical stroke with respect to the detection angle, it is desirable to select a core material such as SUS 430, by

20   which the linearity of the coil impedance can be easily obtained. Furthermore, since the throttle position sensor is disposed in an engine room of the automobile, the detector is required to have a higher upper limit of the operation temperature. Therefore, it is desirable to select the core material, by which the linearity can be easily obtained, and provide an appropriate bias

25   current to the coil, thereby minimizing the influence of a change in angle on temperature characteristic (temperature coefficient).

    In addition, in the case of using the detector as a position sensor for a plant such as power generation facilities, the detector is often subjected to a high temperature. Therefore, it is desirable to use iron chrome as the core

30   material, and provide an appropriate bias current to the coil, thereby

minimizing the influence of a change in angle on temperature characteristic (temperature coefficient).

Additionally, in the case of using the detector as a position sensor for angle detection in motorized bicycles, only one coil portion is often used in the aspect of cost performance. On the other hand, in the case of using the detector as the position sensor for angle detection in automobiles, the double-layered structure of the coil portions is preferable to secure the reliability of the system.

INDUSTRIAL APPLICABILITY

As described above, according to the displacement detector of the present invention, a change in temperature coefficient of the impedance of the coil portion to a displacement of the core can be compensated by using a relatively simple circuit configuration. In particular, when the constant-current circuit is composed of integrated circuit, and setting the constant on circuit is hard to carry out, the present invention is effective. In addition, in the case of using the characteristic-value extracting unit configured to extract a characteristic value (V1) from an output voltage of the coil portion, and a level shift circuit configured to add a level shift voltage (Vsh) to the characteristic value, the purpose of the present invention can be achieved by adding a relative small level shift value to the characteristic value, and therefore it most suitable when the electric-current consumption is limited.

Thus, the displacement detector of the present invention having the above effects is expected to be used in various application fields such as a position sensor for detection of angle used in motorized bicycles or a position sensor for plants such as electric generating facilities as well as a gear position sensor or a throttle position sensor for automobiles.